IV. Frigorific Experiments on the mechanical expansion of Air, *explaining the Cauſe of the great Degree of Cold on the Summits of high Mountains, the ſudden Condenſation of aerial Vapour, and of the perpetual Mutability of atmoſpheric Heat.* *By* Eraſmus Darwin, *M. D. F. R. S.*; *communicated by the Right Honourable* Charles Greville, *F. R. S.*

Read December 13, 1787.

HAVING often revolved in my mind the great degree of cold producible by the well known experiments on evaporation; in which, by the expanſion of a few drops of ether into vapour, a thermometer may be ſunk much below the freezing point; and recollecting at the ſame time the great quantity of heat which is neceſſary to evaporate or convert into ſteam a few ounces of boiling water; I was led to ſuſpect, that elaſtic fluids, when they were mechanically expanded, would attract or abſorb heat from the bodies in their vicinity; and that, when they were mechanically condenſed, the fluid matter of heat would be preſſed out of them, and diffuſed among the adjacent bodies.

As this principle might poſſibly be extended to elaſtic ſolid bodies, as well as to fluid ones, and explain the cauſe of the heat occaſioned by percuſſion or friction, and by ſome chemical combinations, as well as the perpetual mutability of it in

the atmoſphere, I have, at different times, endeavoured to ſubject it to experiment.

1. When Dr. HUTTON of Edinburgh, and Mr. EDGEWORTH of Edgeworthtown in Ireland, were with me about twelve or fourteen years ago, the following experiment, which had been propoſed by one of the company, was carefully made. The blaſt from an air-gun was repeatedly thrown on the bulb of a thermometer, and it uniformly ſunk it about two degrees. The thermometer was firmly fixed againſt a wall, and the air-gun, after being charged, was left for an hour in its vicinity, that it might previouſly loſe the heat acquired in the act of charging; the air was then diſcharged in a continued ſtream on the bulb of the thermometer, and the event ſhewed, that the air at the time of its expanſion attracted or abſorbed heat from the mercury of the thermometer.

In March 1785, by the aſſiſtance of Mr. Fox and Mr. STRUTT, of Derby, a thermometer was fixed in a wooden tube, and ſo applied to the receiver of an air-gun, that, on diſcharging the air by means of a ſcrew preſſing on the valve of the receiver, a continued ſtream of air, at the very time of its expanſion, paſſed over the bulb of the thermometer. This experiment was four times repeated in the preſence of many obſervers, and uniformly ſunk the thermometer from five to ſeven degrees. During the time of condenſing the air into the receiver, there was a great difference in the heat, as perceived by the hand, at the two ends of the condenſing ſyringe; that next the air-globe was almoſt painful to the touch; and the globe itſelf became hotter than could have been expected from its contact with the ſyringe. Add to this, that in exploding an air-gun, the ſtream of air always becomes viſible, which is owing to the cold then produced precipitating the vapour it contained;

contained; and if this ſtream of air had previouſly been more condenſed, or in greater quantity, ſo as not inſtantly to acquire heat from the common atmoſphere in its vicinity, it would probably have fallen in ſnow, as in the fountain of Hiero, mentioned below.

2. About twelve or fourteen years ago, by the aſſiſtance of Mr. WALTIRE, a celebrated itinerant teacher of philoſophy, a thermometer was placed in the receiver of an air-pump, and ſome time being allowed, that it might accurately adapt itſelf to the heat of the receiver, the air was haſtily exhauſted; during which the mercury of the thermometer ſunk two or three degrees, and after ſome minutes regained its previous height. In November 1787, by the aſſiſtance of my very ingenious friend Mr. FORESTER FRENCH, the above experiment was repeated; but with this difference, that the thermometer was open at the top; ſo that the diminution of external preſſure could not affect the dimenſions of the bulb; and the reſult was the ſame, the mercury in the thermometer ſunk two or three degrees, and gradually roſe again. Does not this ſhew, that the air in the receiver, being expanded during the exhauſtion, attracted or abſorbed heat from the mercury in the thermometer?

Both during the exhauſtion, and during the re-admiſſion of the air into the receiver, a ſteam was regularly obſerved to be condenſed on the ſides of the glaſs, which in both caſes was in a few minutes re-abſorbed. This ſteam muſt have been precipitated by its being deprived of its heat by the expanded air: if it could have happened from any other cauſe, the vapour could not, in both ſituations, *viz.* of exhauſtion, and of re-admiſſion, have been taken up again.

3. In December 1784, with the aſſiſtance of Mr. Fox, the following experiment was carefully made. A hole, about the ſize of a crow-quill, was bored into a large air-veſſel, placed at the commencement of the principal pipe in the waterworks which ſupply the town of Derby. The water from four pumps, which are worked by a water-wheel, is firſt thrown into the lower part of this air-veſſel, and from thence riſes to the top of St. Michael's Church into a reſervoir, which may be about thirty-five or forty feet above the level of the air-veſſel.

Two thermometers were previouſly ſuſpended on the leaden air-veſſel, that they might become of the ſame temperature with it; and, as ſoon as the hole was opened, had their bulbs reciprocally applied ſo as to receive the ſtream of air; and the mercury in both of them ſunk two diviſions, or four degrees. This ſinking of the mercury in the thermometers could not be aſcribed to any evaporation of moiſture from their ſurfaces, becauſe it was ſeen, both in exhauſting and re-admitting the air into the exhauſted receiver, that the vapour which it previouſly contained was depoſited during its expanſion.

4. There is a very curious phænomenon obſerved in the fountain of Hiero, conſtructed on a very large ſcale in the Chemnicenſian mines in Hungary, which is very ſimilar to the experiments above related. In this machine the air, in a large veſſel, is compreſſed by a column of water 260 feet high: a ſtop-cock is then opened, and as the air iſſues out with great vehemence, and, in conſequence of its previous condenſation, becomes immediately much expanded, the moiſture it contained is not only precipitated, as in the exhauſted receiver above-mentioned, but falls down in a ſhower of ſnow, with icicles, adhering to the noſel of the cock. This remarkable circum-

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ſtance is deſcribed at large, with a plate of the machine, in the Philoſophical Tranſactions for 1761, Vol. LII.

5. From the four experiments already related; firſt, of the mercury ſinking in the thermometer, by being expoſed to the ſtream of air from an air-gun; ſecondly, from its ſinking in the receiver of an air-pump, during the time of exhauſting it; thirdly, from its ſinking when expoſed to a ſtream of air from the air-veſſel of a water-engine; and, laſtly, from the curious phænomenon of ſnow and ice being produced by the ſtream of expanding air from the fountain of Hiero in an Hungarian mine; there is good reaſon to conclude, that in all circumſtances, when air is mechanically expanded, it becomes capable of attracting the fluid matter of heat from other bodies in contact with it.

Coldneſs of the Summits of Mountains.

Now, as the vaſt region of air which ſurrounds our globe is perpetually moving along its ſurface, climbing up the ſides of mountains, and deſcending into the vallies; as it paſſes along, it muſt be perpetually varying its degree of heat, according to the elevation of the country it traverſes: for in riſing to the ſummits of mountains it becomes expanded, having ſo much of the preſſure of the ſuper-incumbent air taken away, and, when thus expanded, it attracts or abſorbs heat from the mountains in contiguity with it; and when it deſcends into the valley, and is again compreſſed into leſs compaſs, it again gives out the heat it has acquired to the bodies it becomes in contact with.

The ſame thing muſt happen in reſpect to the higher regions of the atmoſphere, which are regions of perpetual froſt, as

was always ſuſpected, and has of late been demonſtrated by the aërial navigators. When large diſtricts of air from the lower parts of the atmoſphere are raiſed two or three miles high, they become ſo much expanded by the great diminution of the preſſure over them, and thence become ſo cold, that hail or ſnow is produced from the precipitated vapour, if they contain any: and as there is, in theſe high provinces of the atmoſphere, nothing elſe for the expanded air to acquire heat from, after the precipitation of its vapour, the ſame degree of cold continues, till the air, on deſcending to the earth, acquires again its former ſtate of condenſation and of warmth.

The Andes, almoſt under the line, reſts its baſe on burning ſands; about its middle height is a moſt pleaſant and temperate climate, covering an extenſive plain, on which is built the city of Quito; while its forehead is incircled with eternal ſnow, coeval perhaps with the elevation of the mountain: yet, according to the accounts of ULLOA, theſe three diſcordant climates ſeldom intrench much upon each other's territories. The hot winds below, if they aſcend, become cooled by their expanſion, and hence cannot affect the ſnow upon the ſummit; and the cold winds, that ſweep the ſummit, become condenſed as they deſcend, and of temperate warmth, before they reach the fertile plains of Quito.

Correſpondence of the Heat of the Atmoſphere with the Height of the Barometer.

From this principle ſome of the ſudden changes of our atmoſphere from hot to cold, aud from dry to moiſt, may likewiſe be accounted for. During the laſt year I frequently obſerved, that when the barometer roſe (the wind continuing

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in the ſame quarter, *viz.* N.E. or S.W.) the air became many degrees warmer. A ſimilar fact is related from MUSSCHENBROEK, in Mr. KIRWAN's ingenious work on the Temperature of different Latitudes; *viz.* that in winter, when the mercury in the barometer deſcends, the cold increaſes. More accurate obſervations on this ſubject, when the air is ſtationary, or when the wind continues in the ſame quarter, might lead to the diſcovery of the quantity of heat ſqueezed out of the air by a certain preſſure.

The Devaporation of aerial Moiſture.

As heat appears to be the principal cauſe of evaporation, as well as of ſolution, and of fluidity in general, the privation of heat may be eſteemed the principal cauſe of devaporation: for though the air may, by its own power of attraction, or by means of the electricity it may contain, diſſolve and ſuſpend a portion of water, as water diſſolves and ſuſpends a portion of ſalt; yet, by the application of cold, theſe are reſpectively precipitated; and therefore heat may be aſſumed as the immediate cauſe of theſe ſolutions. Add to this, that water boils *in vacuo* with leſs heat; that is, it evaporates *in vacuo* faſter or eaſier than in the open air, and therefore the attractive power of the atmoſphere does not ſeem neceſſary to evaporation.

Now, when the barometer ſinks (from whatever cauſe not yet underſtood this may happen) the lower ſtratum of air becomes expanded by its elaſticity, being releaſed from a part of the ſuper-incumbent preſſure, and, in conſequence of its expanſion, robs the vapour which it contains of its heat; whence

that vapour becomes condenſed, and is precipitated in ſhowers, as is viſible in the receiver of an air-pump above mentioned.

There are, however, two other curious circumſtances belonging to the devaporation of water, which have not been perhaps much attended to.

Firſt, that the deduction of a ſmall quantity of heat from a cloud or province of vapour, compared with the quantity of heat which was neceſſary to raiſe that vapour from water, will devaporate the whole. This circumſtance is evident in the operation of common ſteam-engines, in which a ſmall jet of water, whoſe heat is often above 48 degrees, perpetually devaporates the ſteam raiſed by a comparatively very great quantity of heat under the boiler. This difficult problem is explicable from the principles before eſtabliſhed: if a ſmall part of a province of vapour be ſuddenly condenſed, a vacuity takes place, and the contiguous walls of vapour expand themſelves into this vacuity; and thus a large area of vapour, perhaps of many miles in circumference, becomes more or leſs expanded; by this expanſion cold is produced (that is, its capacity of receiving heat is increaſed), and the whole is devaporated.

This very circumſtance exactly takes place in the famous ſteam-engine of Meſſ. WATT and BOULTON; which, from the happy combination of chemical and mechanic power, may juſtly be eſteemed the firſt machine of human invention. In this excellent machine, after the cylinder is filled with ſteam, a communication is opened between this reſervoir of ſteam and a ſmall cell, which is kept cold by ſurrounding water, and free from air by an air-ſyringe adapted to it. What then happens? The corner of the ſteam in the cylinder next to this vacuum (with which it now communicates) ruſhes into it, and the whole ſteam in the cylinder is thus ſuddenly expanded,

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and inſtantly devaporated: whence the very quick reciprocations of the piſton; and that, though the cylinder itſelf is always kept as hot as boiling water, that is, as hot as the ſteam was previous to its devaporation.

Something very ſimilar to this is often ſeen at the commencement of thunder-ſtorms; a ſmall black cloud at firſt appears, in a few minutes the whole heaven is covered with condenſing vapour, and the accumulation or eſcape of electric matter ſeems to be rather the conſequence than the cauſe of this ſudden and general devaporation.

A ſecond curious circumſtance of aërial devaporation is, that when the particles of aqueous vapour begin to approach each other by the diminution of their heat, they do not generate water exactly in proportion to ſuch diminution of heat; but the condenſation proceeds further, and not only a greater quantity of water is produced, but alſo a quantity of heat is ſet at liberty along with this exceſs of devaporation, and the atmoſphere becomes warmer than before the beginning condenſation. This exceſs of devaporation beyond the cold which produced it, is probably owing to the acquired momentum of the aqueous particles towards each other at the beginning of their condenſation, which carries them ſtill nearer each other; and to the ſmall moleculæ at firſt formed, poſſeſſing a greater attractive power over the uncondenſed vapour in their vicinity, and thus preſſing out more of the latent or combined heat.

Concluſion.

1. When a ſmall portion of air, ſuppoſe a few acres, becomes ſuddenly contracted into a leſs compaſs, either by inci-

dental cold, or by any other cauſe not yet underſtood (as the combination of dephlogiſtic and inflammable gaſes), the air next in vicinity ſuddenly expands itſelf to occupy the vacuity; and by its expanſion produces cold and devaporates, and then becomes compreſſible into leſs ſpace than it occupied before it parted with its vapour. This then gives occaſion to the next circum-ambient portion of air to go through the ſame proceſs, that is, to expand, attract the heat from its vapours, devaporate, and then become compreſſible into leſs ſpace; and thus, from a ſmall and partial contraction or diminution of air, it ſeems poſſible to devaporate a great province.

2. The vapour of a great province of air being thus condenſed, would leave a great vacuity in that part of the atmoſphere, which would be ſupplied by winds ruſhing in on all ſides. Suppoſe this to happen to the north of our climate, a ſouth-weſt wind would be produced here, which is otherwiſe very difficult to underſtand: and if it ſhould ever be in the power of human ingenuity to govern the courſe of the winds, which probably depends on ſome very ſmall cauſes; by always keeping the under currents of air from the S.W. and the upper currents from the N.E. I ſuppoſe the produce and comfort of this part of the world would be doubled at leaſt to its inhabitants, and the diſcovery would thence be of greater utility than any that has yet occurred in the annals of mankind.

November 22, 1787.